DRAFT
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Attached is the draft "Air Resources Board Emission Estimation Methodology for Ocean-Going Vessels. This document provides a description of the methodology used to estimate, categorize, and allocate emissions from ocean-going vessels.

This draft is still a **work in progress.** However, it is being released so comments can be made prior to finalizing the methodology. Please do not cite or quote from this draft document, as it is possible that the methodology and the estimated emissions may change based on the comments we receive.

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Emissions Estimation Methodology for Ocean-Going Vessels

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EXECUTIVE SUMMARY

The California Air Resources Board (ARB) staff developed a statewide emissions estimation methodology from ocean-going vessels (OGVs) operating in California coastal waters and California ports and inland waterways. This effort was undertaken to support the development of a statewide emission control strategy addressing emissions from auxiliary engines on ocean-going vessels. The methodology reflects updated population and activity data for ocean-going vessels statewide. Emissions estimates were developed for main and auxiliary engines and eight vessel types, for the year 2004 and projected to 2010 and 2020. As shown in Table ES-1, there were approximately 10,000 vessels visits at California ports in 2004 and almost half of those visits were by container ships.

Table ES-1: Estimated Statewide 2004 Ocean-going Vessel Visits

Vessel Type	Numbers of Visits in 2004
Auto	750
Bulk	946
Container	4744
General	721
Passenger	687
Reefer	52
RoRo	34
Tanker	1941
Totals	9875

Table ES-2 presents the statewide estimate of emission from ocean-going vessels auxiliary engines for 2004. Table ES-3 presents similar information for emissions from the main engines.

Table ES-2: Statewide Emissions from Ocean-Going Vessel Auxiliary Engines in 2004 (tons per day)

Vessel Types	2004 Pollutant Emissions, tons per day				
	PM	NOx	SOx	HC	CO
Auto	0.10	1.11	0.71	0.03	0.08
Bulk	0.35	4.02	2.55	0.11	0.30
Container	1.57	18.11	11.48	0.50	1.37
General	0.15	1.75	1.11	0.05	0.13
Passenger	1.39	14.44	10.24	0.39	1.09
Reefer	0.05	0.60	0.38	0.02	0.05
RoRo	0.03	0.40	0.25	0.01	0.03
Tanker	0.27	3.16	2.00	0.09	0.24
Totals	3.9	43.6	28.7	1.2	3.3

Table ES-3: Statewide Emissions from Ocean-Going Vessel Main Engines in 2004 (tons per day)

Vessel Types	2004 Pollutant Emissions, tons per day				
	PM	NOx	SOx	HC	CO
Auto	0.71	8.49	5.01	0.28	0.65
Bulk	0.82	9.77	5.76	0.32	0.75
Container	10.45	124.32	73.42	4.16	9.60
General	0.50	6.03	3.56	0.20	0.46
Passenger	0.00	0.00	0.00	0.00	0.00
Reefer	0.04	0.50	0.29	0.02	0.04
RoRo	0.18	2.12	1.25	0.07	0.16
Tanker	2.01	23.93	14.13	0.80	1.85
Totals	14.7	175.2	103.4	5.9	13.5

The data in Table ES-4 summarizes the baseline and the projected statewide emissions inventory for diesel PM and NOx from main and auxiliary engines in 2004, 2010 and 2020.

Table ES–4: Ocean-going Vessel Diesel PM and NOx Emission Estimates for Main and Auxiliary Engines for 2004, 2010 and 2020 (tons per day)

Engine Type	2004 Diesel PM	2010 Diesel PM	2020 Diesel PM	2004 NOx	2010 NOx	2020 NOx
Main	14.8	19.0	30.4	175.2	226.4	361.5
Auxiliary	3.5	5.4	10.3	39.5	60.6	112.8
Total	18.3	24.4	40.7	214.7	287.0	474.3

I. BACKGROUND

In this document, ARB staff provides background on the ocean-going vessel emissions inventory, our purpose and goals in preparing an emissions inventory update, and a general overview of the methodology and assumptions used to developed the inventory.

For the purposes of this inventory, an ocean-going vessel (OGV) is a commercial vessel greater than or equal to 400 feet in length or 10,000 gross tons; or propelled by a marine compression ignition engine with a displacement of greater than or equal to 30 liters per cylinder. The emissions inventory includes all OGV emissions occurring within 100 nautical miles of the California coastline. The 100 nautical mile boundary is generally consistent with the California Coastal Waters (CCW) boundary except along the south central coast (Ventura and Santa Barbara Counties) where the CCW boundary is approximately 30 nautical miles offshore.

OGV emissions occur during three distinct operating modes: transit (emissions from vessel operations between ports), maneuvering (slow speed vessel operations while in-port areas), and hotelling (also known as berthing; in-port emissions while moored to a dock).

Two types of engines are found on OGVs, main engines and auxiliary engines. The main engine is a very large diesel engine used mainly to propel the vessel at sea. Main engines are used during the transit and maneuvering modes. Auxiliary diesel-fueled engines on OGVs provide power for uses other than propulsion (except for diesel-electric vessels). Typically, an OGV will have a single, large main engine used for propulsion, and several smaller auxiliary “generator-set” engines. Auxiliary engines are used during all three operating modes. An exception to this configuration is diesel-electric vessels where diesel engine generator sets provide power for both propulsion and auxiliary power needs.

There are a number of types of ocean-going vessels including: auto carriers, bulk cargo carriers, container vessels, general cargo carriers and other miscellaneous vessels, passenger vessels, reefers (refrigerated vessels), roll-on-roll-off vessels (also known as a RO-RO: vessels in which vehicles can be driven on or off the vessel). A list of the different types of ocean-going vessel and a brief description of the goods transported by them presented in Table I-1.

Table I-1: Categories of Ocean-Going Vessels Included in the Emissions Inventory

Vessel Type	Description
Auto	Vessels designed to carry autos and trucks
Bulk Cargo	Bulk carriers are vessels used to transport bulk items such as mineral ore, fertilizer, wood chips, or grain.
Container	Container vessels are cargo vessels that carry standardized truck-sized containers.
General Cargo	Vessels designed to carry non-contaminated cargo such as steal, palletized goods, and heavy machinery.
Passenger	Passenger cruise vessels are passenger vessels used for pleasure voyages.
Reefers	Vessels used to transport perishable commodities which require temperature-controlled transportation, mostly fruits, meat, fish, vegetables, dairy products, and other foods.
RORO	A vessel designed to carry large wheeled cargo such as large off-road equipment, trailers or railway carriages. RORO is an acronym for “roll on/roll off”.
Tankers	Vessels designed to transport liquids in bulk.

Ocean-going vessels are a significant source of diesel particulate matter (PM) emissions and ozone-forming oxides of nitrogen (NOx) in communities near ports. To reduce diesel PM and NOx emissions, ARB staff are undertaking a rulemaking effort to require reductions in emissions from auxiliary engines on OGVs. To support that rule-making and to assist in understanding the impacts from any proposed rule, it is necessary to develop a detailed emissions inventory for OGVs.

The goals of this emissions inventory effort were to:

- Update the inventory to reflect the most current ocean-going vessel fleets;
- Develop a consistent methodology that could be used statewide to estimate emissions from ocean-going vessels;
- Establish a structure that would allow allocation of the statewide emissions to individual ports and Districts; and
- Accurately reflect adopted regulations and other regulatory programs in the baseline inventory and in any future year forecasts.

II. EMISSION CALCULATION METHODOLOGY

In this section, we provide a discussion of the methodology used to develop the ocean-going vessel emissions inventory.

This methodology is similar to the methodology developed by the Starcrest Consulting Group for the Port of Los Angeles Baseline Air Emissions Inventory (2004). (reference 1) As described below, the Starcrest Port of Los Angeles methodology and assumptions were modified in certain instances to incorporate more recent data. The key data sources staff used to develop this inventory were ARB's 2005 Ocean-going Vessel Survey, 2004 California Lands Commission ocean-going vessel visit data, and the ocean-going vessel element of the 2001 Port of Los Angeles emissions inventory.

Emission estimates were developed for three operating modes (transit, maneuvering, and hotelling) and eight vessel types as described in Table I-1. Estimates were made for diesel particulate matter (PM), oxides of nitrogen (NOx), sulfur dioxide (SO_2), hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO_2).

A. Methodology

The basic equation used for estimating emissions from ocean-going vessels is:

$$E_{y,\,t,\,om,\,e} = S\ Pop_{t} * EF_{e,\,om,\,f} * Hrs_{om,\,t} * VP_{om,\,t} * \%Load_{om,\,t}$$

where

E	=	pollutant specific emissions (tons per year of NOx, HC, CO_2, SO_2, and diesel PM)
Pop	=	population of ocean-going vessels by vessel type
EF	=	emission factor by engine type, operating mode, and fuel (units of glkw-hr)
Hrs	=	average annual use in hours by operating mode and vessel type
VP	=	average power by operating mode and vessel type
% Load	=	average engine load by operating mode and vessel type
y	=	inventory year
om	=	operating mode (transit, maneuvering, hotelling)
t	=	vessel type (auto, container, bulk cargo, etc.)
f	=	fuel (HFO or MGO/MDO)
e	=	engine type

Each of these elements, and how they were incorporated into the ocean-going vessel emission estimates, are discussed below. The base year for the ocean-going vessel emissions inventory is 2004.

B. Emission Inventory Inputs

1. Operating Mode

Emissions from OGVs vary based on operating mode. Three operating modes are used to characterize OGV activity: transit (emissions from vessel operations between ports), maneuvering (slow speed vessel operations while in-ports), and hotelling (also known as berthing; in-port emissions while moored to a dock). Main engine emissions occur during transit and maneuvering modes. Auxiliary engine emissions occur during all three modes. Separate emission factors have been developed for main engines in the transit and maneuvering modes. Main engines do not operate during hotelling except for the generator sets on diesel-electric vessels. For the purposes of this emissions inventory, all diesel-electric vessel emissions are reported as auxiliary engine emissions.

2. Vessel Population

2004 California State Lands Commission vessel visits data was used as the primary source of vessel population information. (reference 2) The Lands Commission collects statewide information from the various Marine Exchanges and Port Authorities on vessel port visits and vessels transiting along the California coast. The vessel data collected includes vessel identity, arrival and departure time, port of arrival, last port, and next port. ARB staff used this information to determine the number and type of vessels visiting California ports and transiting within the California emissions inventory zone. Table I-1 identifies the 2004 vessel population by vessel type, number of vessels, and number of visits made by these vessels. As shown in the Table I-1, approximately 10,000 vessel visits occurred in California in 2004.

Table I-1: Estimated Statewide 2004 Ocean-going Vessel Visits

Vessel Types	Numbers of Vessels	Numbers of Visits
Auto	225	750
Bulk	475	946
Container	594	4744
General	196	721
Passenger	44	687
Reefer	19	52
RoRo	13	34
Tanker	372	1941
Totals	**1938**	**9875**

3. Engine Type

Emissions vary depending on the engine type. The two broad classifications of OGV engines are main engines or auxiliary engines. The primary purpose of the main engine is to propel the vessel on the open sea. There are two subcategories of main engines, slow speed and medium speed engines. Slow speed engines are two-stroke engines and are used on 95 percent of all OGVs. (ARB 2005 OGV Survey, reference 7) Medium speed engines are four-stroke and are used on the remaining 5 percent of OGVs. Both types of OGV main engines have different emission rates associated with them. Since the emission rates from slow and medium speed engines vary, staff developed composite emission factors for main engines using information from the ARB's OGV Survey by weighting the emission factors by the appropriate percentage of slow speed (95%) and medium speed (5%) engines.

Auxiliary engines are diesel engines on ocean-going vessels that provide power for uses other than propulsion (except as noted below for diesel-electric vessels). Auxiliary engines are usually coupled to generators used to produce electrical power. Auxiliary engines are used to provide ship-board electricity for lighting, navigation equipment, refrigeration of cargo, and other equipment. Typically, an OGV will have a single, very large main engine used for propulsion, and several smaller auxiliary "generator-set" engines. It was not necessary for ARB staff to develop composite emission factors for OGV auxiliary engines because all were assumed to be medium speed engines.

Passenger cruise vessels, and some tankers, use a different engine configuration which is referred to as "diesel-electric." These vessels use large diesel generator sets to provide electrical power for both propulsion and ship-board electricity. For the purposes of the proposed regulation, and this emissions inventory, these large diesel generator sets are included in the definition of "auxiliary engines."

4. Fuel

OGV emissions also vary based on the type of fuel used. Two fuel types, marine distillate [marine gas oil (MGO) and marine diesel oil (MDO)] and heavy fuel oil (HFO), are used in OGVs. For main engines, staff assumed all OGVs were using HFO. This is based on information reported in the ARB's 2005 OGV Survey which indicated that 99 percent of main engines were using HFO. According to the Survey, 29 percent of the auxiliary engines used marine distillate and 71 percent used HFO, except for passenger vessels that use approximately 8 percent marine distillate and 92 percent HFO.

The ARB 2005 OGV survey also collected information about the average sulfur content of the fuels used by OGVs. From the Survey, the sulfur content of HFO averaged 2.5 percent sulfur while the distillate ranges from 0.03 – 1.5 percent sulfur with an average 0.5 percent.

5. Emission Factors

Emission factors for OGVs vary by pollutant, operating mode (transit, maneuvering, or hotelling), engine type (main engine/slow speed, main engine/medium speed, or auxiliary/medium speed), and fuel type (HFO or marine distillate). Emission factors for diesel particulate matter (PM), oxides of nitrogen (NOx), sulfur dioxide (SO_2), hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO_2) were compiled. Emission factors for ocean-going vessels are expressed as grams of pollutant emitted per kilowatt-hour of energy (g/kW-h).

Tables I-2, I-3, and I-4 below present the emission factors used in the development of the ocean-going vessel emissions inventory. Table I-2 presents the emission factors for OGV main engines during transit or high load operation while at sea. As shown in the table, a composite emission factor was developed to take into the account the differences in emissions between the slow speed (two-stroke) and medium speed (four-stroke) engine. This was done by weighting the emission factors by 95 percent for slow speed engines and 5 percent for medium speed engines.

Table I-3: Main Engine Emission Factors – Transit Mode (g/kW-hr)

Engine Type	Fuel Type	PM	NOx	SO2	HC	CO	CO2
Slow Speed	HFO	1.5	18.1	10.5	0.6	1.4	620
Medium Speed	HFO	1.5	14	11.5	0.5	1.1	677
Composite EF	HFO	1.5	17.9	10.6	0.6	1.4	623

Table I-4 presents the emission factors for OGV main engines during maneuvering or low load operation near ports. Again, a composite emission factor was developed to account for the differences in emission between slow speed and medium speed engines.

Table I-4: Main Engine Emission Factors – Maneuvering Mode (g/kW-hr)

Engine Type	Fuel Type	PM	NOx	SO2	HC	CO	CO2
Slow Speed	HFO	1.5	14.5	11.6	1.8	1.4	682
Medium Speed	HFO	1.5	11.2	12.7	1.5	1.1	745
Composite EF	HFO	1.5	14.3	11.7	1.8	1.4	685

Table I-5 presents the emission factor for OGV auxiliary engines, including diesel-electric vessels. As shown in the table, the emission factors for auxiliary engine vary depending on the type of fuel used.

Table I-5: Auxiliary Engine Emission Factors – Transit, Maneuvering, and Hotelling (g/kW-hr)

Engine Type	Fuel Type	PM	NOx	SO2	HC	CO	CO2
Medium Speed	HFO	1.5	14.7	12.3	0.4	1.1	722
Medium Speed	Marine Distillate	0.3	13.9	2.1	0.4	1.1	690
Medium Speed	Marine Distillate @0.1% S	0.25	13.9	0.4	0.4	1.1	690

The emission factors for both main and auxiliary engines used by ARB staff are generally consistent with the emission factors used by *Starcrest* in developing the 2001 Port of Los Angeles emissions inventory. (Reference 3). The *Starcrest* emission factors were based on work done by *Entec*. The *Entec* emission factors were developed using *Lloyd's of London* and *IVL Swedish Environmental Institute* data that related emissions to engine speed and the type of fuel used. The *Entec* emission factors also relied on earlier work done by *Arcadis* in 1999 and *Accurex*. (Reference 4), (Reference 5)

The *Starcrest/Entec* emission factors are an improvement over the *Arcadis* and the *Accurex* emission factors because they reflect more recent test results. These emission factors also account for an increase in emissions at lower loads. This allows for more accurate estimates of main engine emissions during maneuvering where an engine load as low as 2 percent was observed.

Staff adjusted the emission factors for PM and SOx to reflect the average sulfur content of HFO obtained from 2005 OGV survey. ARB staff elected not to use *Starcrest/Entec* emission factors for PM for auxiliary engines using HFO. ARB staff also developed an emission factor for CO to supplement the *Entec* emission factors.

ARB staff developed an alternative PM emission factor for auxiliary engines using HFO. Instead of the *Starcrest/Entec* emission factor for PM of 0.8 g/kW-hr for auxiliary engine using HFO, ARB staff used a PM emission factor of 1.5 g/kW-hr. Staff believes that the *Starcrest/Entec* emission factor was too low based on the results of calculations based on a U.S. EPA methodology. (EPA, 2004) Based on that methodology, the sulfate PM fraction by itself was estimated to be approximately 0.8 g/kW-hr. In addition, several other sources (Environ Report and Sine Mersk Testing Report) support using a higher emission factor for auxiliary engines using HFO.

The emission factor developed was based in part on work reported by *Environ.* The emission factor was then adjusted to reflect updated information on sulfur content and break specific fuel consumption for HFO. *Environ* reported a PM emission factor of 1.74 g/kW-hr for medium speed, four-stroke engines using HFO. This emission factor was based on a HFO with a sulfur content of 3 percent and a brake specific fuel consumption of 222 g/kW-hr. Staff adjusted the emission factor to account for the lower average sulfur content of HFO reported in the 2005 ARB OGV Survey (2.5 percent) and a lower brake specific fuel consumption of 210 g/kW-hr.

For CO emissions from the main engines during transit, staff elected to use a U.S. EPA emission factors published in the *Environ* report. (Reference 6) This emission factor is consistent with the CO emission factors used by *Starcrest* for the Port of Los Angeles emission inventory.

6. Operating Time – Time in Mode

Time in mode is the total amount of time that a vessel operates in a particular mode. To estimate emissions, it is necessary to determine the average time vessels spend in transit, maneuvering, and hotelling by vessel type.

<u>Transit Time</u>

Transit time is estimated by dividing the length of the transit by the average vessel speed. The length of the transit (in miles) associated with each vessel trip listed in the Lands Commission data was estimated using US Army Corps of Engineers (USACE) National Waterway Network map data (reference 8). Since the shipping lanes in the National Waterway Network are intended as either actual or representative shipping lanes, it was necessary to adjust the shipping lanes and the route distances to reflect actual routes where the USACE routes were not accurate. For example, shipping traffic bound for Northern Asia ports follow the “Great Circle Route”, which passes through the Santa Barbara channel and then travels northwest. This is different from how the trip is typified by the USACE data. The USACE data has those vessels traveling a southwesternly route.

ARB staff plan to supplement the National Waterway Network data with geographic data obtained from the NOAA International Comprehensive Ocean-Atmospheric Data Set (ICOADS). The ICOADS data are meteorological and geographic data collected from participating vessels and can be used to infer vessel routes. This data is currently being analyzed by Dr. James Corbett of the University of Delaware under contract with the ARB. The inventory will be revised as this data becomes available.

Average vessel speeds were obtained from the *Starcrest* report, which used a proprietary Lloyds of London vessel information database to calculate average vessel speed by vessel type. *Starcrest* also used data from a vessel boarding program that allowed the direct measurement of vessel speeds, as well as other vessel characteristics such as maneuvering time and load factors. These speeds, average vessel data, are summarized in Table I-6.

Table I-6: Main Engine Characteristics - Transit

Vessel Type	Average Vessel Speed (knots)	Average Vessel Speed (mph)
	Transit	Transit
Auto Carrier	18.7	21.5
Bulk	14.5	16.7
Container Ship	22.6	26.0
General Cargo	15.6	18.0
Passenger	19.2	22.1
Reefer	20.1	23.1
RO-RO	14.8	17.0
Tanker	14.7	16.9

Source: Port of Los Angeles Baseline Air Emissions Inventory
Passenger Vessels use the same engines for propulsion and auxiliary power

Maneuvering Time

Maneuvering times from the Port of LA were assumed representative for all ports statewide. The average maneuvering time by vessel type was obtained from the *Starcrest* report (reference 1). Maneuvering times were determined based upon direct observation in the vessel boarding program. Table I-7 summarizes the maneuvering times used to develop the emissions inventory. As port specific maneuvering times become available, they will be incorporated into the OGV inventory.

Table I-7: Auxiliary Engine Characteristics – Time In Mode (hours)

Vessel Type	Transit	Hotelling	Maneuvering
Auto Carrier/RORO	x	45	3
Bulk Carrier/General Cargo	x	88	2
Container Ship	x	48	2
Passenger	x	11	1
Reefer	x	60	3
Tanker	x	38	2

Hotelling Time

Average hotelling times were obtained from the 2005 ARB OGV survey and are shown in Table I-7. For the Ports of LA, Long Beach, and Oakland, vessel specific hotelling times were used. These hotelling times were obtained from time in port data provided by the port Marine Exchanges. For LA and Long Beach, the time in port included maneuvering times, so the hotelling times were calculated by subtracting the maneuvering time from the time in port. For all other ports in California, the average hotelling times were used to calculate emissions.

7. Vessel Power

Vessel power is the total power of a vessel's engines. Often there is a single main and multiple auxiliary engines. For this inventory, these engines are represented as the total power of either the main or the auxiliary engines.

Main Engines

Table I-8 summarizes the main engine power characteristics. These power estimates were obtained from the *Starcrest* report, which used a proprietary *Lloyds of London* vessel database to calculate average main engine power by vessel type. Essentially all main propulsion engines in ocean going vessels are compression ignition engines that burn heavy fuel oil. Although there were at least seven steam turbine powered ships still in operation in 2004, they are declining in number and their emissions are not specifically estimated here.

Passenger vessels and a few tankers use diesel-electric engines for both propulsion and auxiliary power; emissions calculations for these vessels were adjusted to avoid double counting by assuming all emissions occurred from auxiliary engines. In 2004, only a few diesel-electric tanker, were in operation, but others are planned for service.

Table I-8: Vessel Main Engine Power Characteristics (kilowatts)

Vessel Type	Average Power
Auto Carrier	10,700
Bulk	8,000
Container Ship	30,900
General Cargo	9,300
Passenger	46,700
Reefer	9,600
RORO	11,000
Tanker	9,400

Source: Port of Los Abgeles Baseline Air Emissions Inventory
*Passenger vessels use the same engines for propulsion and auxiliary power

Auxiliary Engines

Electrical power for an OGV is generally provided by auxiliary and diesel generator sets during transit maneuvering and hotelling. However, in some cases, electrical power can be provided by a shaft generator on the main engine. At dock power is generally provided by only the auxiliary engines.

In the case of tankers transporting crude oil, the crude oil is generally pumped using steam-driven pumps; the steam is provided by a boiler. As mentioned above, all passenger vessels and a few tankers obtain their electrical power from their main diesel-electric engines.

Table I-9 summarizes the power characteristics of auxiliary engines. The auxiliary engine power profiles were obtained from the 2005 ARB OGV Survey (reference 7).

Table I-9: Vessel Auxiliary Engine Power Characteristics (kilowatts)

Vessel Type	Average Vessel Power
Auto Carrier/RORO	2,850
Bulk Carrier/General Cargo	1,776
Container Ship	6,800
Passenger	46,670
Reefer	3,900
Tanker	1,985

Load Factor

The main engine load factor for transit mode was estimated to be 80%; the main engine load factor during maneuvering was estimated to be 2 percent, as shown in Table I-10, for auxiliary engines, the load factors very depending on vessel type and operating mode. The auxiliary engine load factor represents the actual engine power used divided by the total installed auxiliary engine power. All load factors were obtained from the *Starcrest* report and were developed by the Port of Los Angeles from the results of the vessel boarding program.

Table I-10: OGV Auxiliary Engine Load Characteristics (percent load)

Vessel Type	Load Factor (%)		
	Hotelling	Maneuvering	Transit
Auto Carrier/RORO	26%	45%	15%
Bulk Carrier/General Cargo	10%	45%	17%
Container Ship	18%	50%	13%
Passenger	16%	64%	80%
Reefer	32%	45%	15%
Tanker	26%	33%	24%

C. Emission Projections

Emission projections for the years 2010 and 2020 were developed. These projections reflect expected growth rates in the ocean-going vessels populations and activity; changes in emission factors over time as the new engine standards are implemented, and the fleet turn over. Below, ARB staff describes the assumptions used to generate the emission projections for future years.

1. Growth Factors

Future year vessel population estimates were developed based on work done by Dr. James Corbett of the University of Delaware. Dr. Corbett has developed growth factors based on vessel type and by air basin. The methodology differs from the methodology used by ARB in CEIDARS and by *Starcrest* in the Port of Los Angeles emissions inventory. The revised methodology estimates growth based on the changes in the installed power of vessels for the years 1997-2003. The growth rates selected are the midpoint between the best fit compounded annual growth rate in vessel power between 1997 through 2003 and the best fit linear (arithmetic) growth rate in vessel power for the same time period. The estimated growth rates, from the 2004 levels, by vessel type for 2010 and 2020 are presented in Table I-11.

Table I-11: Growth Rates, By Vessel Type, for 2010 and 2020 (base year – 2004)

Vessel Type	2010	2020
Auto Carrier	15%	43%
Bulk Carrier	-27%	-67%
Container Ship	39%	130%
General Cargo	-9%	-24%
Passenger	94%	496%
Refrigerated Vessel	1%	3%
RORO	15%	43%
Tanker	29%	92%
Total - All Vessel Types	**20%**	**90%**

2. New Engine Standards

The annex VI emission standards, that were ratified in 2005, are projected to result in very little change in the fleet average in the foreseeable future. As such, the emissions inventory did not project any emissions reductions due to these standards.

III. EMISSION ESTIMATES

A. Statewide Emission Estimates

The emission inventory for ocean-going vessel includes total statewide emissions. The data in Table I-12 summarizes the statewide inventory for diesel PM by engine type and operating mode for 2004, 2010, and 2020.

Table I-12: OGV Diesel PM Emissions for Main and Auxiliary Engines for 2004, 2010, and 2020 (tons per day)

Engine Type	Operating Mode	2004 Diesel PM	2010 Diesel PM	2020 Diesel PM
Main	Transit	14.7	18.9	30.2
Main	Maneuvering	0.1	0.1	0.2
Total Main		14.8	19.0	30.4
Auxiliary	Transit	1.6	2.5	5.8
Auxiliary	Maneuvering	0.2	0.3	0.5
Auxiliary	Hotelling	1.7	2.6	4.0
Total Auxiliary		3.5	5.4	10.3
Main + Auxiliary		18.3	24.4	40.7

The data in Table I-13 summarizes the statewide inventory for oxides of nitrogen (NOx) by engine type and operating mode for 2004, 2010, and 2020.

Table I-13: OGV NOx Emissions for Main and Auxiliary Engines for 2004, 2010, and 2020 (tons per day)

Engine Type	Operating Mode	2004 NOx	2010 NOx	2020 NOx
Main	Transit	174.7	225.7	360.4
Main	Maneuvering	0.5	0.7	1.1
Total Main		175.2	226.4	361.5
Auxiliary	Transit	17.5	26.5	61.6
Auxiliary	Maneuvering	2.2	3.3	5.7
Auxiliary	Hotelling	19.8	30.8	45.5
Total Auxiliary		39.5	60.6	112.8
Main + Auxiliary		214.7	287.0	474.3

The above inventories do not include emissions from boilers. Many OGV have small boilers that produce steam used to heat heavy fuel oil We believe that this is a relative minor source of emissions compared to the main and auxiliary engine emissions. These emissions will be assessed as more data becomes available. Tables I-15, I-16, and I-17 at the end of this sections presents the 2004, 2010, and 2020 emissions inventory by operating mode, engine type and vessel type.

B. District-specific Emission Estimates

In order to estimate district-specific growth rates, ARB staff examined the growth in both vessel calls and engine size per vessel between 1997-2003. This surrogate, installed vessel power, is expected to be directly proportional to emissions generated by ocean-going vessels. ARB staff evaluated this surrogate, and found projected growth in this surrogate to be consistent with growth rate estimates developed by the Port of Los Angeles for their No Net Increase report. As a result, growth rates projected by the Port of Los Angeles in that report were applied to both the Ports of Los Angeles and Long Beach. For ports outside of Los Angeles, ARB staff developed an average growth rate based on the installed power surrogate.

Table I-14 presents the estimated growth rate calculated by air basin based on the installed power surrogate within that air basin. The air basin specific growth rates were applied to in-port emissions: hotelling, maneuvering, and transit emissions within three miles of the coast of the California coast. Transit emissions that occur in the Outer Continental Shelf (OCS) (beyond the three mile limit out to 100 miles) cannot be tied directly to a single port. As a result, vessel type-specific growth factors were used. The vessel type-specific growth factors were also be used where port-specific factors are not available, such as passenger vessels calling in Monterey.

Table I-14: Growth Rate by Air Basin (base year – 2004)

Air Basin	2010	2020
South Coast	51%	108%
Bay Area	39%	133%
San Diego	91%	486%
South Central Coast	34%	111%
San Joaquin Valley	48%	171%
Sacramento	11%	30%
North Coast	-75%	-91%

For purposes of modeling, OGV emissions will be allocated to specific grid cells based on the National Waterway Network data. The ARB CEIDARS emission inventory database requires emissions occurring in the OCS Air Basin to be assigned to specific counties and specific air pollution control districts. It is important to note that meteorology defines how OCS emissions impact land; assignment of specific OCS areas to counties and districts is done for database reasons, and not to indicate that a specific county or district is either responsible or impacted by a specific OCS area. There exists no official federal or state governmental assignment of OCS waters to specific counties or air basins. Currently, emissions are allocated on the basis of spatial allocation factors developed by Sonoma Technology, Inc. (STI), under contract to the ARB (See reference 9 and map 1). The STI spatial surrogate accounts for all emissions within 100 miles of the coast; assignment of portions of the OCS to various counties was done by extending county boundaries due west where possible. In Southern California, however, these county waters assignments were redrawn for this inventory so that the Los Angeles and Orange county portions of the OCS corresponded to the *Starcrest* Port of LA inventory study area.

Transit emissions were spatially allocated by assigning vessel emissions to the vessel route along the shortest path found in the National Waterway Network. As stated previously, modifications were made to the shipping lanes to reflect actual conditions.

All transit emissions beyond the three mile limit are assigned to the OCS air basin. Transit emissions within the three mile limit and within the San Francisco Bay are assigned to the appropriate air basin.

Maneuvering and hotelling emissions were assigned to the port where the activity takes place, except for tanker hotelling emissions in the Pacific Lightering Area, which were assigned to the OCS air basin.